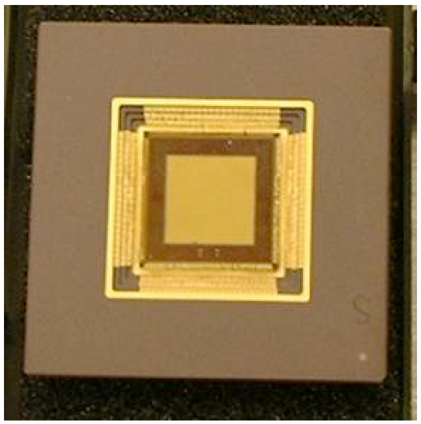
Advanced Deformable MEMS Mirror Systems for the Terrestrial Planet Finder Mission



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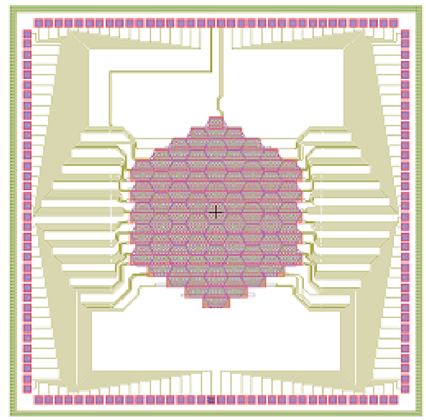
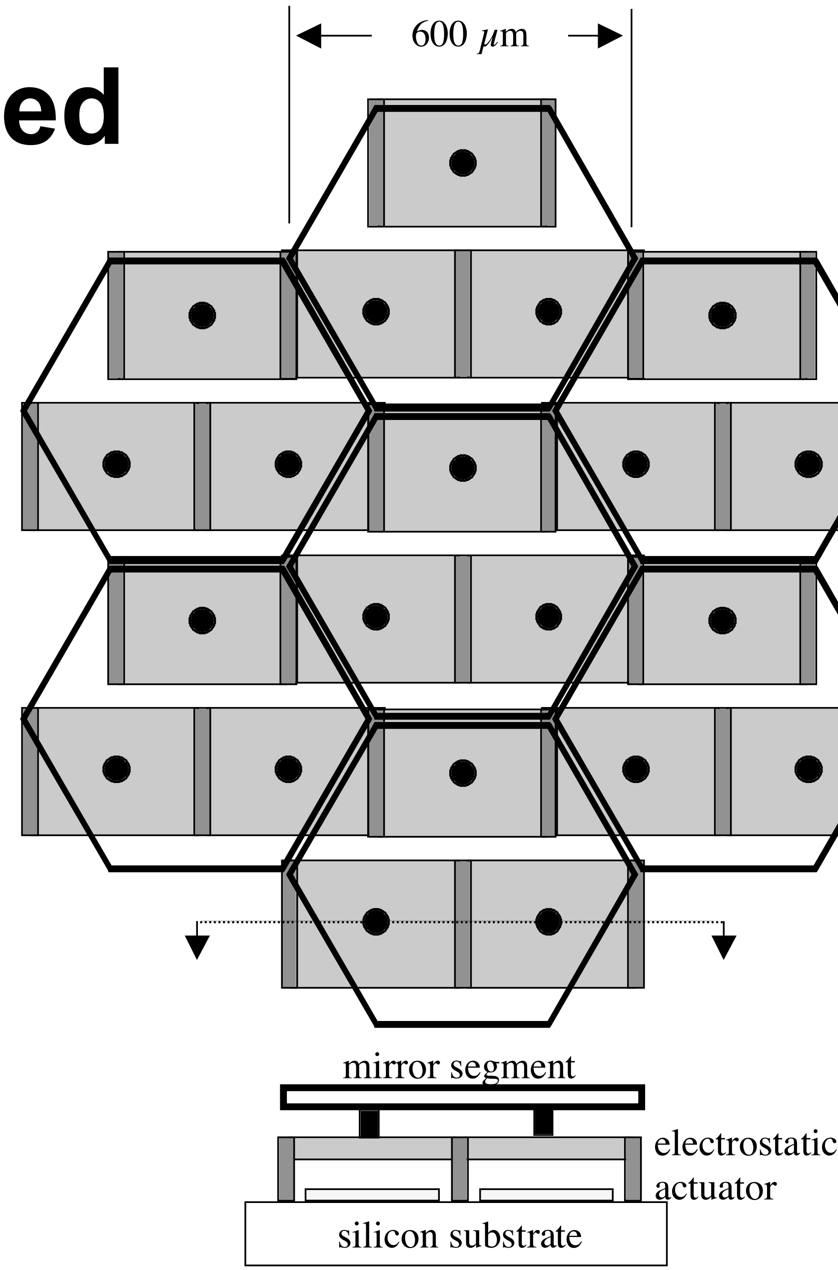
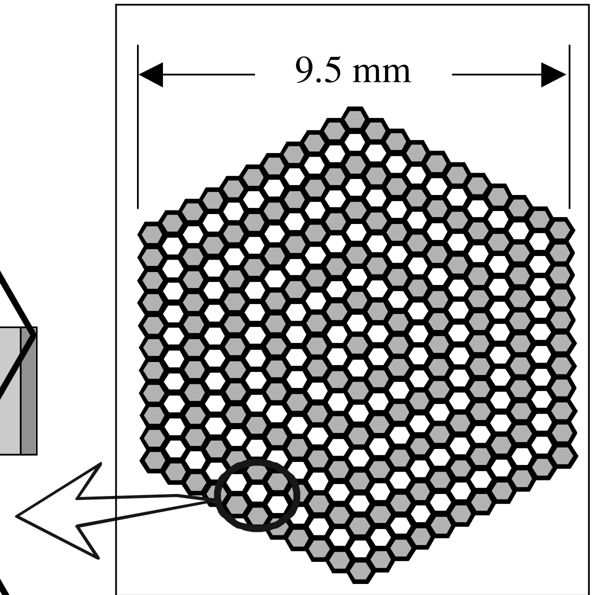
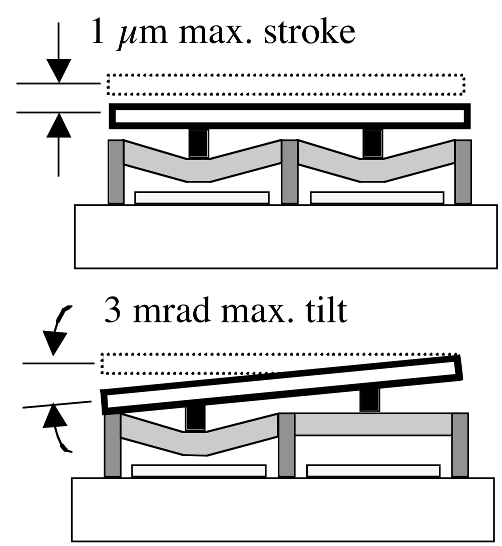


Proposed DM Design







TPF Deformable Mirror for Visible Nulling Coronagraph Testbed

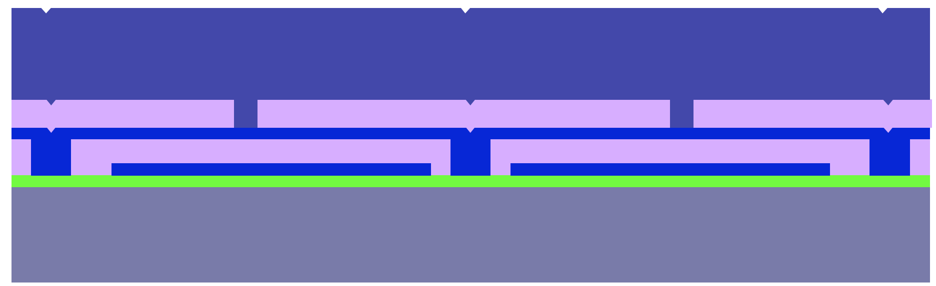
- Independent tip-tilt-piston for phase *and amplitude* control of each subaperture
- Suitable for space-based operation (compact, low power, radiation hard)

Characteristics of the proposed device

Mirror architecture	329 close-packed hexagonal segments
Actuation architecture	Electrostatic tip/tilt/piston control for each segment
Segment geometry	600µm hexagons, 15µm thick
Segment motion (piston)	1 µm range, 0.1nm resolution (open loop)
Segment motion (tip/tilt)	600 arc-second range, 0.06 arc-second resolution
Segment flatness	< 1 nm RMS
System electronic driver	External (w/ technology path to integrated driver)
Package geometry	25mm x 25mm x 5mm ceramic pin grid array

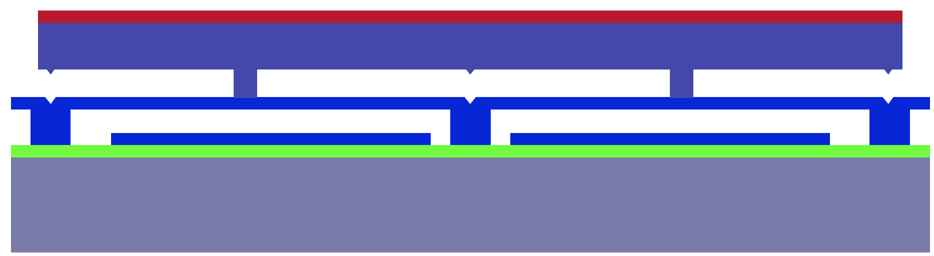
Significant Technical Challenges

- Mirror segment flatness (< 1 nm RMS)
  - 15 μm epitaxial polysilicon deposition and etch
  - Chemomechanical polish



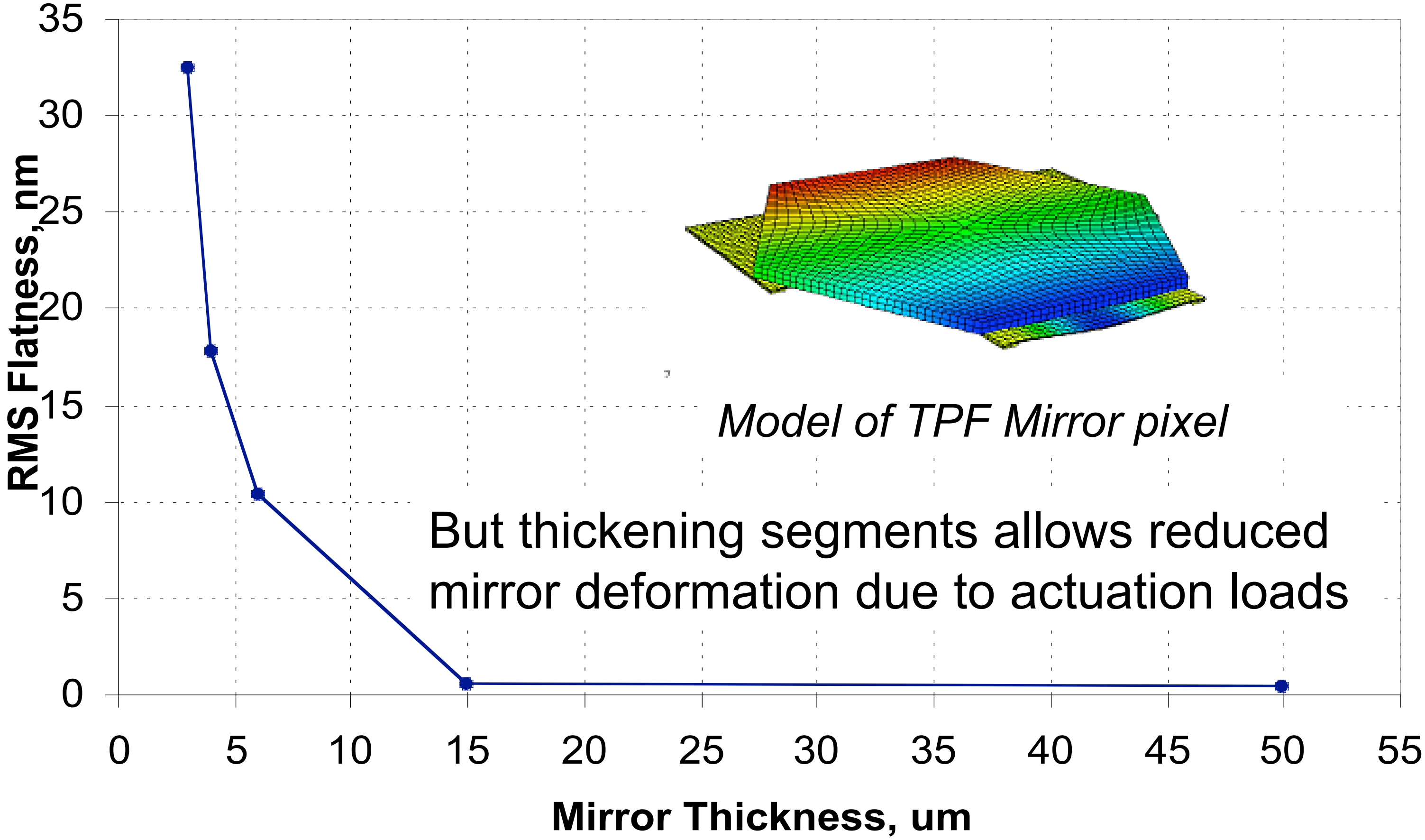
Unreleased mirror cross section (one segment)

- Positioning precision (< 1 nm) and low power operation
  - Integrated ultra-precise electronic drivers



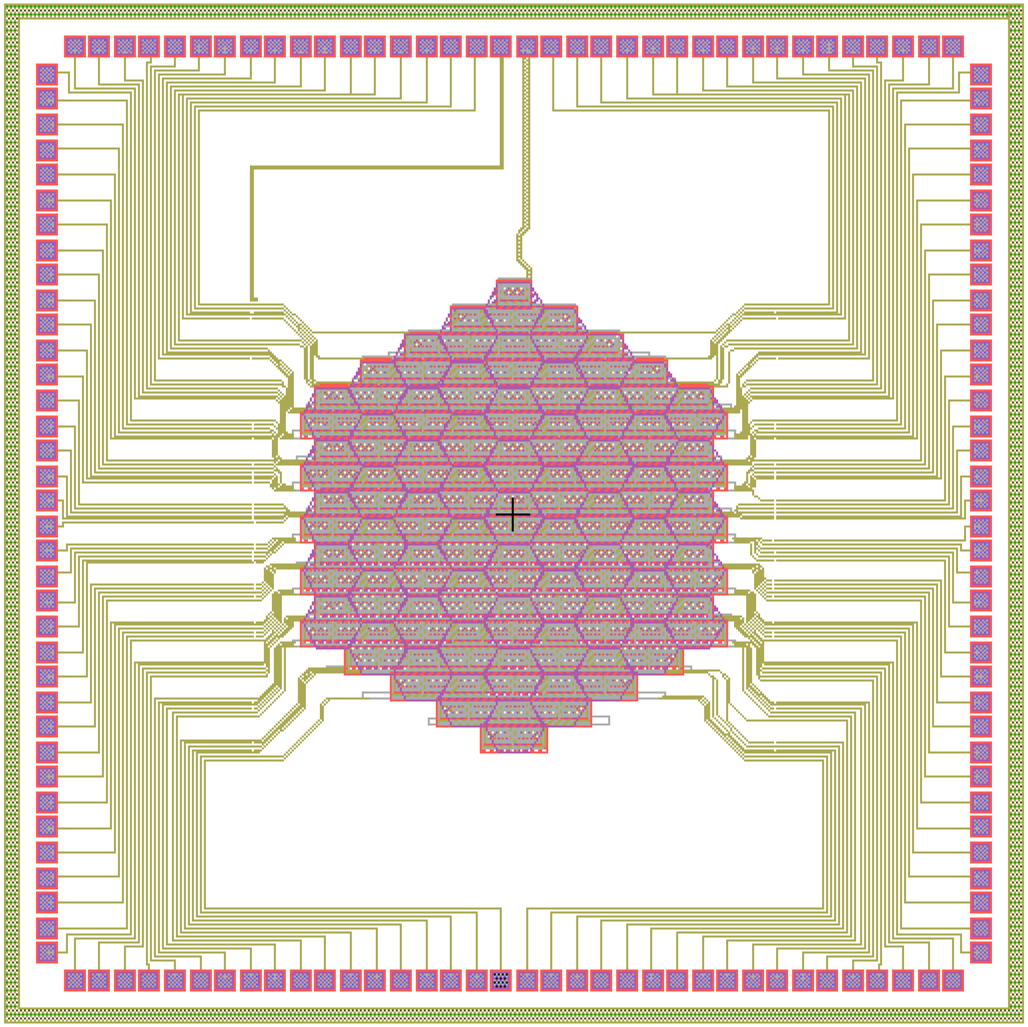
Released mirror cross section (one segment)

Tilting Deforms Segments



15 μm is a very thick MEMS film…

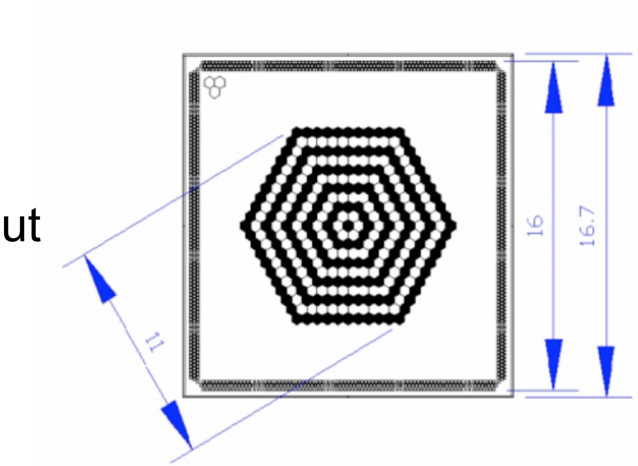
61 Pixel TPF Array

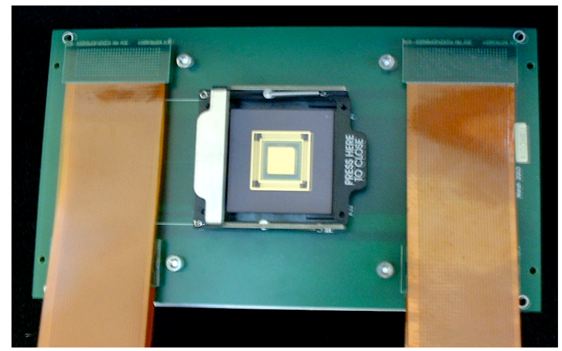


Mask designs complete: Mirror in fabrication now at MEMS silicon foundry

Technology Demonstration System

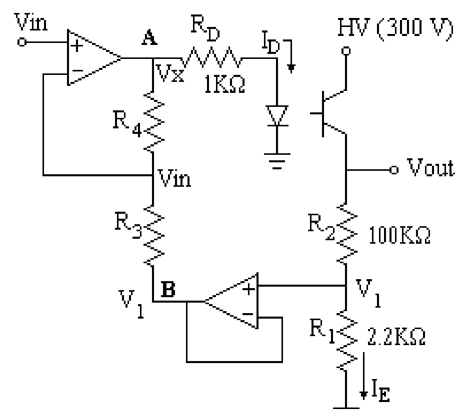
329 segment chip layout





Package, custom mounting board, and high-density flex cables

High voltage, high-precision array driver



High-voltage amplifier

Project Review Questions

Can the deformable mirror be provided with a continuous face sheet?

Yes, the mirror can be provided with a continuous instead of a segmented face sheet. (as a result, these MEMS DMs can be adapted to TPF applications beyond visible nulling coronagraph)

What are the issues involved in attaining a higher resolution (< 0.1 nm)?

Resolution of 0.1 nm over 1µm stroke will require:

Closed loop feedback on each segment

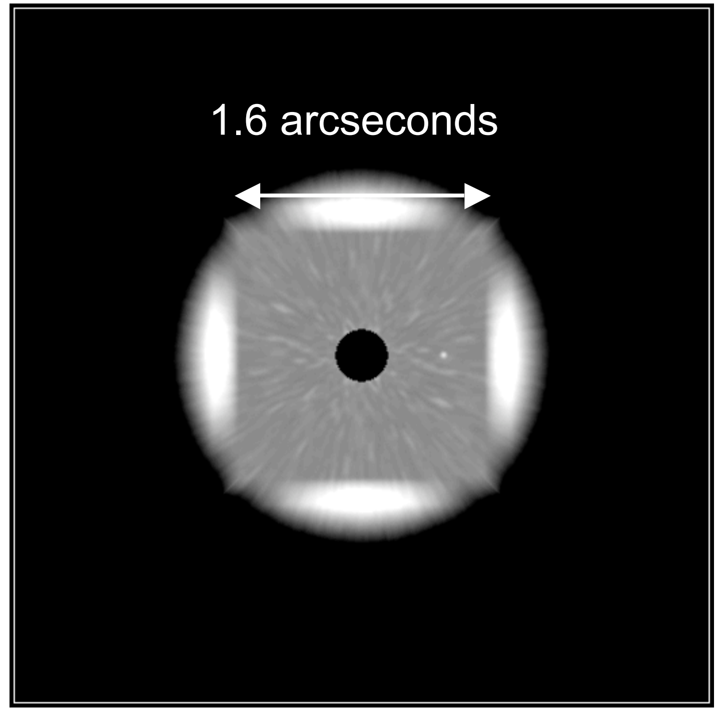
Shielding of wire routing lines to reduce x-talk .

What is the stability versus time of the actuator position?

The proposed actuators have been measured over several days, and hundreds of millions of cycles. In the worst case, the standard deviation of mirror position (with open loop control) was found to be about five nanometers.

eXtreme Adaptive Optics Planet Imager: XAOPI

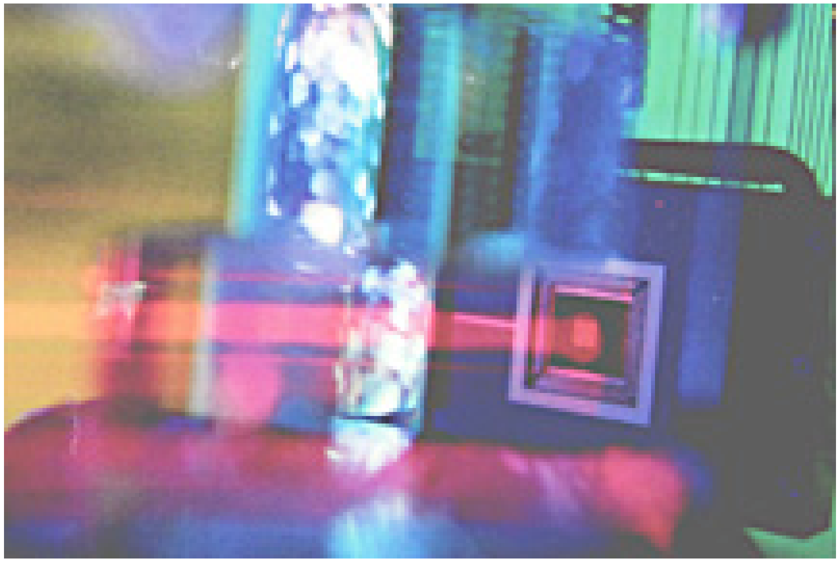
- Ultra-high contrast AO system for Keck telescope sponsored by the NSF Center for Adaptive Optics
- 4096-actuator continuous-facesheet MEMS
- Science goal: direct detection of warm extrasolar Jovian planets
- 2002-3 MEMS testing to take place at UCSC Laboratory for Adaptive Optics (1024 actuator MEMS now, 4096 in 1-2 years); could be deployed in 2007
- XAOPI would provide real-world testing of MEMS phase control
- LLNL, UC Berkeley, UCSC, UCLA, Caltech, JPL team (posters at TPF Expo)



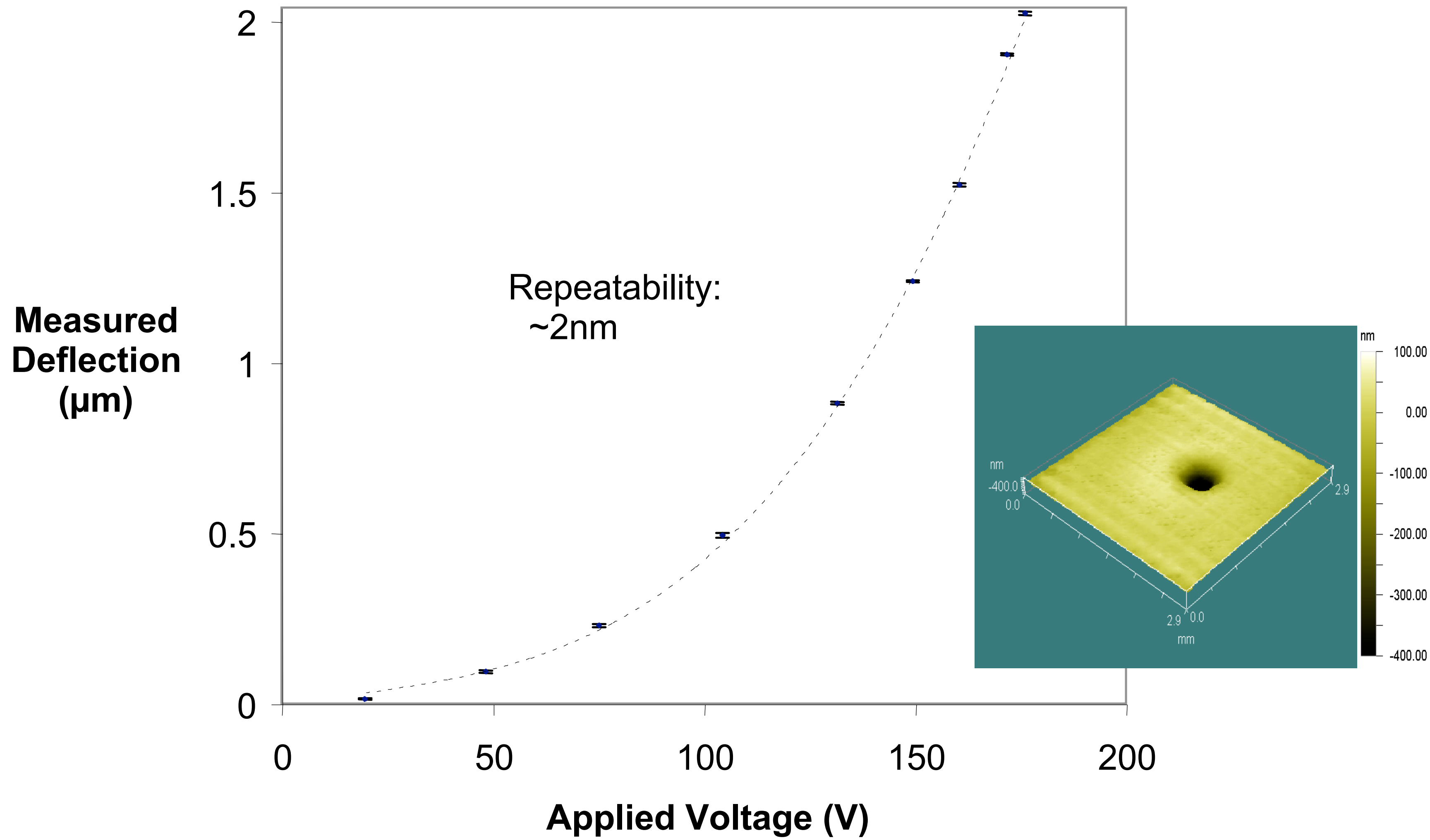
Simulated 15 minute XAOPI H-band image showing a 8 Jupiter-mass planet near a solar-type star

Current Status of BU/BMC Kilo-Pixel DMs

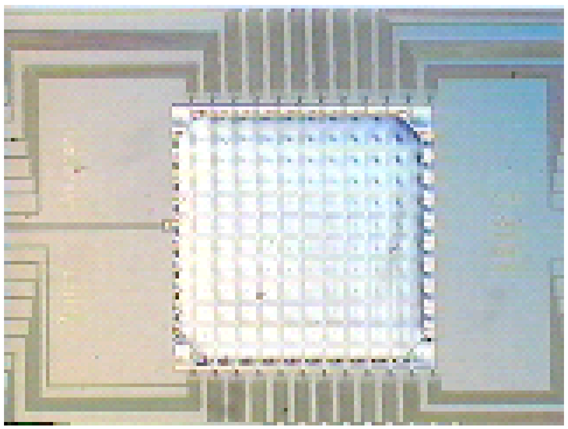
- 1024 elements
- 2 μm stroke
- 10nm RMS mirror surface flatness
- 2nm pixel motion repeatability
- 10mm clear aperture
- Wire bonded for off-chip electronics



µDM actuation is precise and repeatable in open loop



Deformable Mirror Summary



MEMS DMs promise significant promise in TPF missions and earth-based extreme adaptive optics:

- *Scalable* to thousands of actuators
- *Precise* and repeatable
- *Compact* and low power
- *Resistant* to radiation damage